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MULTIMEDIA COMMUNICATIONS CAPABILITY

Richard C. Butler II

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Air Force Systems Command
Griffiss Air Force Base, NY 13441-5700

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This report discusses the progress made during 1987 on a Rome Air Development Center (RADC) in-house project titled, "Multimedia Communications Capability," (M^2C^2). The objective of this program is the development of a multimedia testbed that will be used to examine specific communications and networking issues. The primary concern is the intelligent use of all existing communications assets, which is critical during a conflict. Secondary considerations involve the expansion of current capabilities through the use of packet radio technology and the unification of networks by an Intelligent Communications Controller (ICC). The multimedia testbed will allow the development of techniques and advance the state-of-the-art so that significant progress can be made toward meeting future needs in communications.

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INTRODUCTION

Radio communications have been recognized as a critical resource for the defense and preservation of peace for the American people and their allies against man-made and natural disasters. The military of the United States depends greatly upon reliable and efficient communications to defend this country against aggression. It is imperative that they have the best possible communications available to them to facilitate their mission of defense, especially during the trans- and post-attack timeframes. This is when communications traffic will maximize and resources will minimize due to enemy activity. Despite the proliferation of networks over various media, it is probable that communications will saturate and even the highest priority items might not get through to the users. The ability to communicate at this time will have an extensive impact on the effectiveness in repulsing an enemy attack and the reconstitution of forces to continue the fight.

The concept of multimedia communications is intended to address this critical issue and to supply an essential capability to the armed forces. This concept entails the use of several networks and media as one unified and intelligently controlled network, providing a larger throughput than the sum of its constituent networks. Much work has been done in this area and is continuing in the private sector. Such programs as the Air Defense Initiative by Harris Corporation, the Media Resource Controller by Hughes Aircraft Company, and the Survivable Adaptive Planning Experiment, which has yet to be awarded, are all working this important problem. The Multimedia Communications Capability (M^2C^2) project at Rome Air Development Center (RADC) is a Directorate of Communications (DC) in-house project intended to provide a tactical capability which can be employed while it is being developed, to determine the specific needs for the Air Force and the other services, to help the engineers at RADC to keep pace with developments

in this area, and to influence the direction of research taken by the private sector.

PROBLEM

Simply stated, communications assets are primary targets of aggression since they are such a critical resource for those that defend this country. The enemy will make every effort to destroy, degrade, or control communications and communications equipment in any way possible. Presently, the majority of military communications is highly vulnerable to enemy attack. The biggest threat is posed by a high altitude nuclear burst where the electromagnetic pulse (EMP) could disrupt certain media for days. Even equipment that remains intact could be rendered useless in the area of such a burst. Combined with this is the threat of actual attacks on communications facilities, whether it be by physical destruction or electronic countermeasures (ECM), such as jamming or spoofing. Any successful attack will lead to a degraded, incomplete, or even a partitioned network. Despite the existing redundancy of networks, some nodes will be unable to talk with certain other nodes. Combine this degradation with the massive increase in traffic and significant contention will be experienced as each node fights to get a message into the network. There exists a dire need for a capability to link various networks and media together, thereby increasing connectivity and throughput.

OBJECTIVE

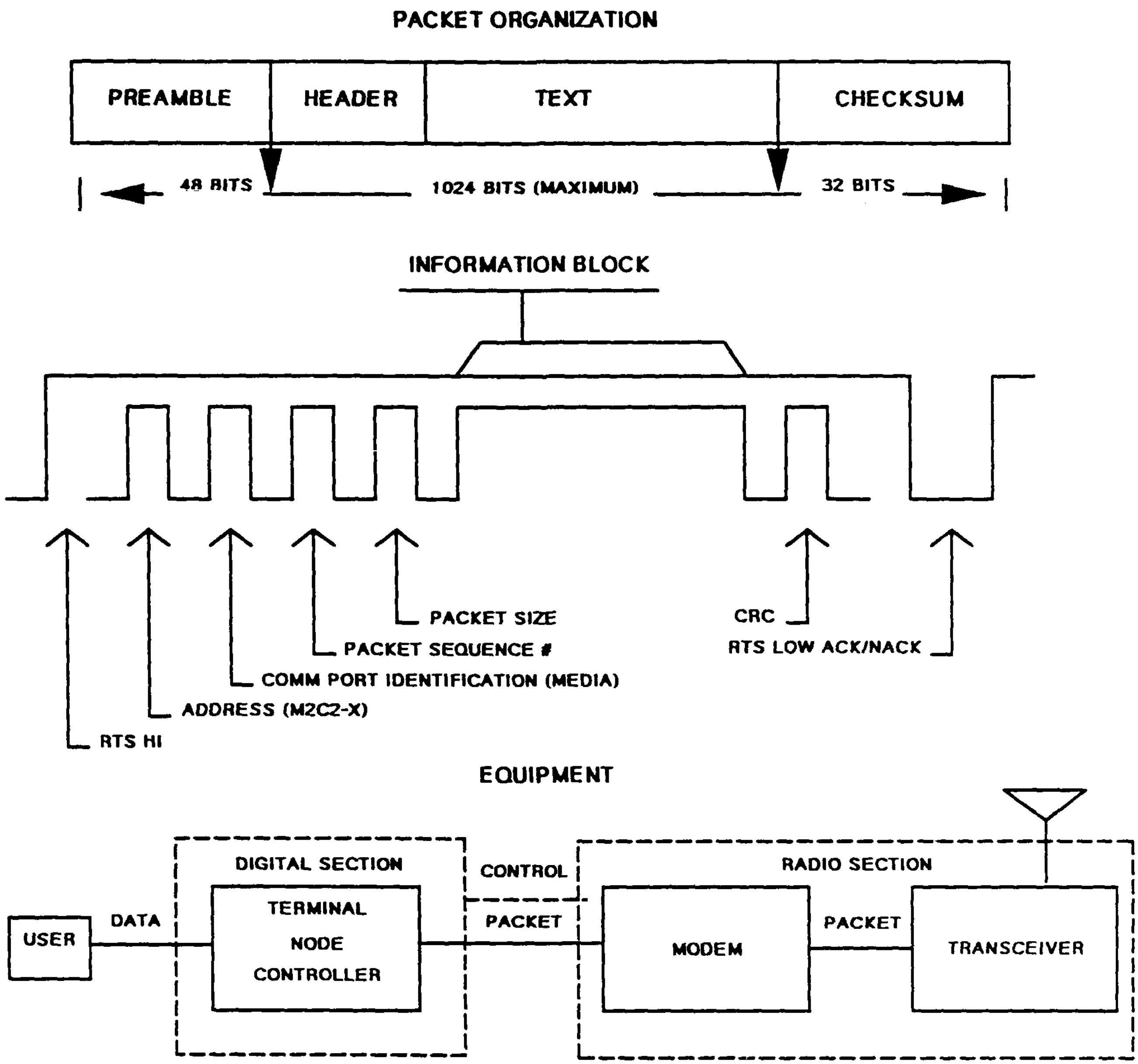
The objective of this in-house project is to develop a capability that will unify the various transmission networks and nodes, increasing the capacity of the existing communications resources, and maximizing throughput. This capability will be developed from scratch and involve

the use of as much off-the-shelf equipment as possible since there is already too much diversity. Packet radio technology (Figure 1) will be utilized to provide error-free communications, while software-driven network control will be used to simplify operation and increase flexibility. The facility will be housed in mobile shelters to increase survivability and utility. Such a facility will link all of the RADC in-house laboratories and off-base sites together into a convenient testbed to examine critical communications issues. The final objective is to investigate the requirements for an intelligent multimedia resource controller (MRC) which will automatically optimize communications.

In 1987, radios from the high frequency (HF), very high frequency (VHF), and ultra-high frequency (UHF) portions of the spectrum will be integrated into a system, along with a high speed modem and a personal computer to control them all. Software will be written that will packetize outgoing data, select a radio to transmit the data, and send the data from the send side. On the receive side, the software will open the file received, acknowledge the transmission, and enter the received data into the file. This software will also vary the packet size according to the link conditions and automatically switch media to complete a transmission upon failure of the initial link. Other issues that will be addressed include store-and-forwarding of data in intermediate nodes, forward error correction (FEC), and alternate routing due to a busy or failed link along the primary or shortest path.

APPROACH

Our approach is to negate the perceived threats to reliable communications as effectively, yet as inexpensively as possible. Many networks and a massive amount of equipment have already been fielded, yet the total capability of this equipment is not nearly realized. We



- O PACKETIZES INPUT
- O SENDS OUT PACKET
- O ACKNOWLEDGES SUCCESSFUL RECEIPT FOR EACH PACKET PRIOR TO SENDING NEXT PACKET

FIGURE 1. TYPICAL PACKET RADIO TECHNOLOGY

plan to use as much off-the-shelf equipment as possible to demonstrate that if the existing equipment and networks are integrated into a larger, intelligent network, then the resulting multimedia system will perform admirably even in the most hostile environment. Despite attacks on certain facilities and transmission media, such a system will reconfigure and transform itself so that communications traffic may continue. When the damage is repaired, the system will again reconfigure to take advantage of all available resources.

To accomplish these objectives, a computer controlled system is envisioned that takes advantage of state-of-the-art packet radio technology and multimedia network control. Multiprocessing will allow media sensing, variable length packetization, signal processing, message queuing, and optimized routing to all be carried out simultaneously in each media. This will greatly increase throughput and efficiency. Furthermore, the use of packet radio technology and intelligent routing will reduce or eliminate several, if not all, of the threats to communications and result in a very robust and survivable system.

PROGRESS

This project was begun in April 1986, and after much preparatory work, tangible progress was made by the end of the year (Figure 2). Two radio systems, the Harris RF-155DR Data HF Radio Set and the Collins AN/GRC-171B UHF Radio Set, were installed into the mobile shelters and interfaced to the newly acquired Zenith Z-248 computers. Also, a second HF radio system, the Harris RF-350K, was being installed. The capability to transfer ASCII files in a multimedia configuration was demonstrated. There was very little success, however, in the transfer of binary files, which is an essential feature of the proposed system.

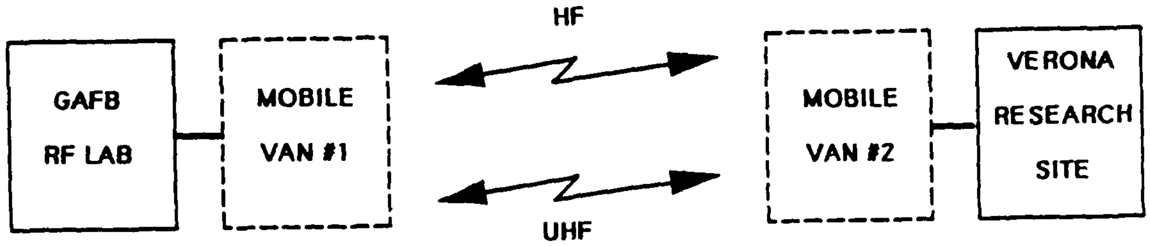


FIGURE 2. MINIMUM CAPABILITY OF A MULTIMEDIA TESTBED, DEC 86

After experimenting with several modems such as the Frederick 1280R FSK, the Hayes 2400B, the Hayes 1200, an older model of the Hayes 1200, and the Pakratt PK-232 packet modem, it became apparent that none of these were suitable for this dual application. Fortunately, the Harris RF-3466 high speed modem was on order and arrived shortly thereafter. This modem allows the interfacing and computer control necessary for the operation of a multimedia packet network. The addition of new software, written to exploit the features of the Z-248 and RF-3466, would enable the problems of such a network to be more actively pursued in 1987.

In Jan 87, preparations were made to operate and test the installed systems over a significant distance. Previously, over-the-air work was confined to a single site. Griffiss Air Force Base and the Verona Test Annex, separated by about 15 miles, were planned to be the principal sites for testing. A HF whip antenna was installed onto the 90-foot tower outside of Building 3 at Griffiss. The antenna coupler was mounted in the attic of the building and cables were run to connect the antenna, the coupler, and the computer. This configuration resulted in high reflected power. A representative of Harris Corporation speculated that problems could be arising from the coupler being located too far from the antenna, approximately 92 feet, or that the location of the coupler caused a strange antenna pattern in the attic. It was decided to mount the coupler on the tower next to the antenna. Brackets were

fabricated and the installation was accomplished, along with the running of new cables. A short test with the Verona site yielded good results. Other work in the RF Lab in Building 3 entailed the installation of the Harris RF-3466 modem into the equipment rack located there and the fabrication of interconnect cables for the radios and the computer.

Similar work on an antenna, coupler, and RF cable was done at Verona's Lab 2. Also, work continued to install the recently acquired Harris RF-350K HF radio system into the mobile van temporarily located at Verona. The RF-350 transceiver was tested and it checked out properly. Experimentation continued with the RF-3466 to establish keyline control of the transmitter, an essential feature of the envisioned system. Other work included the fabrication of an AC power cable to supply the power from Lab 2 to the mobile van. Also, a 208V AC outlet was installed in the mobile van for a space heater which would allow the van to be left outside of the lab without damaging any of the equipment.

In February, a computer scientist from Rome Research Corporation began software development to allow the computer control necessary for such a packet network to operate. Commercial software did not offer the flexibility required. Control of the radio keyline was quickly obtained and work began on the packetization of data and checksums. By the end of the month, the software allowed any file, ASCII or binary, to be sent out over HF. The transmit end would send the filename, packet size, the data, and a checksum. The receive end would read the filename, open the file, set the packet size, read the data, compare the checksum, and send an acknowledgement (ACK) or non-acknowledgement (NACK) to the transmit end, depending upon the integrity of the data measured by the checksum. Attempts were made to test the software over UHF with the GRC-171. These were unsuccessful, however, as the microphone jack in the front of the radio could not be interfaced. Plans were made to try the TADIL-C access in the back of the radio.

In the meantime, much work was being done on the equipment. The Harris RF-3466 modem was modified by the installation of the RF-3407 Soft Decision Kit. The modem was then interfaced to the RF-350. Software problems were encountered in the RF-350 because of damage incurred during shipment. Replacement software was obtained from Harris and installed. The RF-7110 Adaptive Controller was then programmed for the authorized frequencies and the appropriate types of modulation. It then seemed to properly control the RF-350 and the RF-601A antenna coupler. Other hardware problems experienced were with the RF-155 system. A touchy 120V breaker on the bottom of the rack was replaced. Later, an attempt to power up the system resulted in the absence of a power light. It was discovered that the windings of a transformer were open, thereby cutting power to the system. Problems were also encountered with the RF-590 radio. The radio would not pass its self-test. Troubleshooting began by removing a module for the preselector. The problem cleared itself and the unit passed its self-test, even after replacing the module. Heat was suspected as the cause of this intermittent problem as the receive module was very hot.

In March, these problems were corrected. A new transformer was installed into the antenna coupler. Also, a capacitor was replaced in the receive portion of the RF-590. That seemed to correct the heat problem.

Since it is envisioned that each media will eventually use a separate modem, a Frederick 1280 modem was installed into the UHF system. Cables were fabricated to interface the modem to the GRC-171 and to the Z-248. The modem was experimented with for two weeks using the computer. The system software was modified and many avenues were explored unsuccessfully. It became apparent that this modem was inappropriate for this project. The concept of a modem for each media was maintained (and is to-date); however, because of cost and availability limitations, a compromise was in order. A switchbox was

designed and fabricated so that each media could use the single RF-3466 modem. With only two media currently operating, such a device was not too complex. However, the complexity would increase greatly for each media added. Cables were fabricated to interface this device to the radios, the modem, and to the computer.

The ultimate packet radio system involves a great deal of equipment. Previously, all of the equipment was being stuffed into the Harris RF-350 system racks. However, with the additional equipment and even more anticipated shortly, these racks became obsolete. For this reason, a trip was made to Harris Corporation, Rochester NY, to obtain Harris 6-foot racks.

In April, all of the equipment and racks were removed from van #2 in preparation of the new layout. Baseplates were fabricated and hat channels were attached to the wall of the shelter for the new racks. The Harris RF-350 racks were reinstalled, along with two additional Harris 6-foot racks. These were shock mounted to the floor and to the wall of the shelter. The RF-155DR system, the RF-3466, and the GRC-171 were all installed into the 6-foot racks. The RF-350 system was replaced into its original racks. System checkouts revealed that the UHF radio had a shorted AC, in-line filter which was replaced. A small table was also bolted to the floor of the van onto which the Z-248 was secured. Additional cables were made to interface the computer to the radios and to the modem.

Back at the RF laboratory, work continued on the switchbox. The cables for the switchbox were installed and the device was tested. It was fc nd that the HF keyline operated at 28 volts DC instead of at grcun as first thought. The switchbox was then rewired to use a transistor instead of an integrated chip (IC). In the next test run, the HF i the UHF keylines had feedback on each other. Again, the switchbox was rewired. This time, separate wires were used on each

keyline. Also, a Reed relay was added into the HF keyline. With these changes, the device properly controlled the HF and UHF keylines. Diagrams were drawn of this latest configuration of the equipment and the switchbox.

With the switchbox in the system and operating correctly, unsuccessful attempts were made to pass data. The switchbox circuits and ICs were all bypassed, yet the results were the same. After troubleshooting the system, it was determined that a wire was on the wrong pin inside the modem. The wire was resoldered correctly and the system could then pass data. The change was noted on the drawings. A second switchbox was then made and installed into van #1. Interconnect cables were also fabricated and installed. The systems were brought up and data was passed successfully over HF.

Attempts to pass traffic over UHF, through the front microphone jack were still unsuccessful. The system was rewired to the J22 jack in the back of the UHF radio, for TADIL operation. This was also unsuccessful. The J22 jack was then reworked into TADIL A operation. The modem would then work properly, but a timing problem still existed with the computer. A slight adjustment to the switchbox corrected this problem and everything seemed to work properly.

In May, plans were made to take van #2 out to the Youngstown Test site in western New York State, for a full month of long distance over the air testing in June. Van #2 was selected because it had just been configured into the most advanced system the project had developed to date. In addition to all the logistical and clerical preparations, van #2 was transported to Griffiss and tested repeatedly to ensure that everything was in perfect working order so as not to lose any precious time in troubleshooting and maintenance in the middle of the testing period.

Simultaneously, van #1 was transported to Verona Lab 2 where all of the equipment was removed and placed in the laboratory. This would serve dual purposes. First, the equipment was set up in the lab so that it could act as the local end of the testing. An important advantage to this situation was the collocation of troposcatter gear and personnel experienced in operating it for years between Verona and Youngstown. Secondly, upon conclusion of the testing, the equipment could be returned to van #1 in the same configuration as it had been installed in van #2.

In June, van #2 was taken to the Youngstown site to start the testing. Mixed results were obtained at first, partially due to the varying weather conditions. The testing in the latter part of the month was more successful and it soon became routine. Data on the transfers was taken throughout the month. The engineers and technicians involved with the testing gained valuable experience from the operator's viewpoint, which would facilitate future developments. At the conclusion of testing, the site was closed up and the van was returned to Griffiss.

In July, more maintenance was required on the equipment located in the RF lab and out at Verona. In the RF lab, the RF-1310 had no RF output. The problem was isolated down to a pin diode. The diode was replaced and the exciter seemed to work properly. The RF-3466 also had a problem in the form of a bad PC card. A new card was ordered from Harris. The preselector unit was repaired as well. Other work in the RF lab involved the system check of the RF-7110, which had yet to be utilized.

Out at Verona, trouble was experienced with the GRC-171. The ready light would not come on at all of the frequencies. A 90-degree extender board was fabricated to aid in the troubleshooting. The synthesizer had a phase lock loop error on the bad frequencies. The problem was located

in the synthesizer board. The board was replaced and all of the frequencies were all right, but a radio check with the RF lab turned out to be 2x2 (readability and understandability). A cable or antenna problem was suspected. The RG-214 antenna cable and the antenna were replaced. A voice check with Griffiss then registered a 5x5. Other work at Verona was in preparation of the installation of the new racks into van #1. The 220V lines were rewired to accommodate the full-size racks and the air conditioner that was to be installed shortly. The RF-350 racks were unbolted from the floor of the van for the reconfiguration. Also, new hat channels and spacers were made to secure the RF-350 racks in their new location.

In August, the reconfiguration of van #1 continued. Hat channels and a base plate were fabricated for a second and third rack. These racks were secured to the floor and the wall of the shelter with the use of shock mounts. The electrical run in the shelter was extended to the front of the van for power to the air conditioner. The van was then taken to Griffiss where the air conditioner was installed; the van was then returned to Verona.

Meanwhile, back in the RF lab, work continued with the RF-7110 Autolink adapter. In the process of hooking it up to the RF-155 system, it was learned from Harris that the RF-601A antenna coupler and the RF-1310 power amplifier would not support the Autolink without significant modifications. This posed an important dilemma. All of the previous work and software development was directed toward the use of the RF-155 system. On the other hand, the Autolink is a very important capability that allows the scanning of available HF frequencies. If it was to be incorporated into the multimedia project, either the RF-155 system would have to be heavily modified or much work would have to be repeated for the utilization of the RF-350K system. It was decided to do the latter. Parts were ordered for the appropriate broadband antennas, cables were constructed to connect the computer interface unit

(CIU) to the radio, and the RF-350K system was installed into the racks in the RF lab. The transceiver was programmed for the link scan, cables were made to interface the RF-7110 to the computer and the RF-3466, and experiments began between the lab and van #1 at Verona. The CIU was installed into one of the equipment racks and connected to the radios. The function that it performs is to interface the RS-232 port of the computer to the RS-422 ports of the radios. Hardware and software work began so that the unit could be used. Finally, not willing to forfeit all the previous work or have to choose one HF system or the other for the project, a patch panel was designed that would switch between the RF-155 system and the RF-350K system.

Other work in the RF lab was involved with the integration of a Harris RF-3090 VHF radio into the multimedia system. The VHF radio was powered up and it checked out to be operational. A remote speaker was built and installed to help the engineers and technicians figure out what was going on during transmissions, not only on VHF, but also on HF and UHF. A keyline isolation module was built to obtain keyline control, which was a necessity as it was with the HF and UHF radios. The keyline interface box had to be modified to accommodate the VHF radio. The device would now interface three ports at different keying voltages to the computer port, allowing simultaneous keyline control of the three radios.

In September, the construction, troubleshooting, and testing of the keyline buffer box were completed. A second box passed through this procedure and was installed into van #2. Drawings for the latest buffer box were made and updated with the changes from the troubleshooting. The patch panel for the RF-7110 was also installed into van #2. It was tested and a link quality analysis (LQA) was run. Another patch panel for the CIU at Verona was constructed. Also, a CIU local control unit (LCU) was researched for the VHF and UHF radio systems.

HF, VHF, and UHF near-vertical incident skywave (NVIS) antennas, AS-2259, were added to the multimedia facility during the month. An antenna mounting stand was designed and manufactured for the roof of Building 3. The stand was erected and the antennas were assembled on top of the building. Another set of antennas were assembled at Verona. A ground plane was also installed on top of Building 3. These antennas were tested and it was found that they worked better without a balun.

Work in and with van #2 was impeded during the month by construction that had begun in the vehicle bay area where the van was temporarily kept. The construction forced the relocation of the van to the rear of the bay where no power hook-up was available. A request was submitted to Base Civil Engineering to supply the necessary power in that part of the bay. In the meantime, some supply orders were filled out and some maintenance work was accomplished. An audio problem and a problem with the high power amplifier (HPA) of the RF-155 system existed. The audio problem turned out to be a simple bad connection. The problem in the HPA was determined to be bad transistors in the power supply. These transistors were replaced and the system worked well. Representatives of the Harris Corporation also did some work on the system at this time. They modified the RF-7110 firmware to improve its performance when used with the RF-350.

Also during the month of September, the personnel on the multimedia project were requested for support by the Directorate of Command and Control (CO). The engineers there were working on an in-house project involving a Tactical Air Request Network (TARN), better known as close air support for ground troops. Previous response times had been deemed inadequate due to difficulties in communications and interservice coordination. This effort was aimed at simplifying requests for air support, thereby decreasing response times. The personnel of the multimedia facility were committed to working with these engineers to accomplish their objectives and to demonstrate an improved capability by

the end of November, 1987. Research on the communications flow in and out of the Tactical Air Control Centers (TACCs) was the first task completed in support of the TARN demonstration.

In October, the NVIS antennas were experimented with to obtain optimum performance. The antennas at Verona were moved to check for blockage, without much change. The RF-350 was operated with poor results, both at Griffiss and Verona. Excessive voltage standing wave ratios (VSWRs) were experienced at both ends of the link. Various antenna configurations were then tested at Griffiss. The best results were obtained with an inverted "V," half-rhombic configuration, which was end fed and end loaded. The antennas were used with a balun and external resistors to show a constant impedance at all frequencies. The VSWR seemed good at 2:1 or less. The same configuration was implemented at Verona.

An expansion of the testbed for the multimedia project was made by including the Ava Test Site as a location from which to operate. Previously, Verona and Griffiss were the only sites used, except for the month of testing at Youngstown. A location for van #1 was surveyed at Ava and van #1, now operational, was moved there from Verona. A power box was moved from the roof of the building there and positioned near the van. The van was powered up and it checked out to be operational. An LQA was performed between Ava and the RF lab.

The removal of van #1 from Verona left this site without sufficient communications equipment to take part in any tests. This equipment was replaced by the equipment that was located in the RF lab. With van #2 at Building 3, three nodes now existed: Ava, Verona, and Griffiss.

Work continued on three of the most important devices to the operation of the multimedia system: the keyline buffer box, the patch panel, and the CIU. Each was updated and tested. Each node required

one of each of these devices for proper operation. Duplicates and interface cables were made to meet the requirements. A printer was added to the RF-7110 Autolink so that it could be used more effectively. Data was taken hourly from the LQA to become familiar with its operation and to attempt to establish daily trends. More cables were made to integrate the VHF radio into the system. More speakers were built, along with speaker panels, so that communications traffic could be monitored at each node. A fiber optic unit was installed into van #2 to add to its capability and speed in passing traffic.

Also during October, delivery was taken on three Motorola, UNIX-based, VME System 1131s. These systems offer a high speed, multiprocessing capability which will greatly increase the effectiveness and speed of the multimedia system. The Zenith Z-248s functioned as tools for software development and file servers in anticipation of the arrival of the VMEs. The VMEs were unpacked and inventoried upon arrival. One of the systems was set up in the RF lab to begin familiarization. Very little documentation was available on the systems and this made progress very difficult and slow. Interface cables were built to connect the VME to the RF-350. Other work on the VMEs would be delayed until after the TARN demonstration at the end of November.

In November, messages were passed daily between Griffiss, Ava, and Verona in order to identify and correct any potential problems with the current system and to determine if any improvements could be made. Early in the month, the VHF radio (the RF-3090) failed and would not complete its self-test. All possible front panel checks were performed without discovering the cause of the failure. Harris Corporation was contacted and they suggested that the three processor boards be changed. The radio was returned to Harris where they found and replaced a bad memory board. When the radio was returned and reinstalled at Verona, it operated well at 5x5. The RF-7110 was operated extensively to obtain and analyze performance data on the NVIS antennas. The antennas at each

site were checked to see if any modifications could be performed to improve communications. The HF antenna at Verona was realigned to give better coverage to Ava and Griffiss. The VHF antenna at Verona was taken down from the pole on which it was mounted. A bracket was fabricated for the roof installation of a HF whip antenna. The antenna was raised and connected with an appropriate cable. Software development and maintenance continued. The XFER program, the program that controls the multimedia system operation, was updated to result in a marked improvement. The CO directorate had their own software program called NET, which was investigated to determine how it would be used with the multimedia system. Other software work included the correction of a software setting in the RF-3466 to allow for a 900 millisecond (ms) delay in the keyline and the testing of the CIU software and firmware.

Work continued on the keyline buffer boxes, the patch panels, and the CIUs. The keyline buffer box was constructed more professionally out of circuit boards, a chassis board, and plugs, after its design had been refined. Another patch panel was constructed, along with additional interface cables. Cables were also fabricated for CIU testing and to interface the RF-7110 to the RF-350 radio.

In December, attention shifted from the TARN, after a successful demonstration, back to strictly multimedia. The quality of the links between Griffiss, Ava, and Verona was still not satisfactory. It was decided to take full advantage of the RF-7110 by trying a wide range of NVIS antenna configurations and selecting the one that gave the best overall results. The RF-7110 was operated daily and the data was entered into the computer for analysis. Eight baluns were ordered for use with the NVIS antennas. The balun at Ava was changed and the VSWR was determined to be high on two frequencies. A jumper was put across the mast connector with slightly better results. The load resistor was removed with no change, so it was replaced. A new balun was also installed at Verona and Griffiss. The mast was shorted as it was done

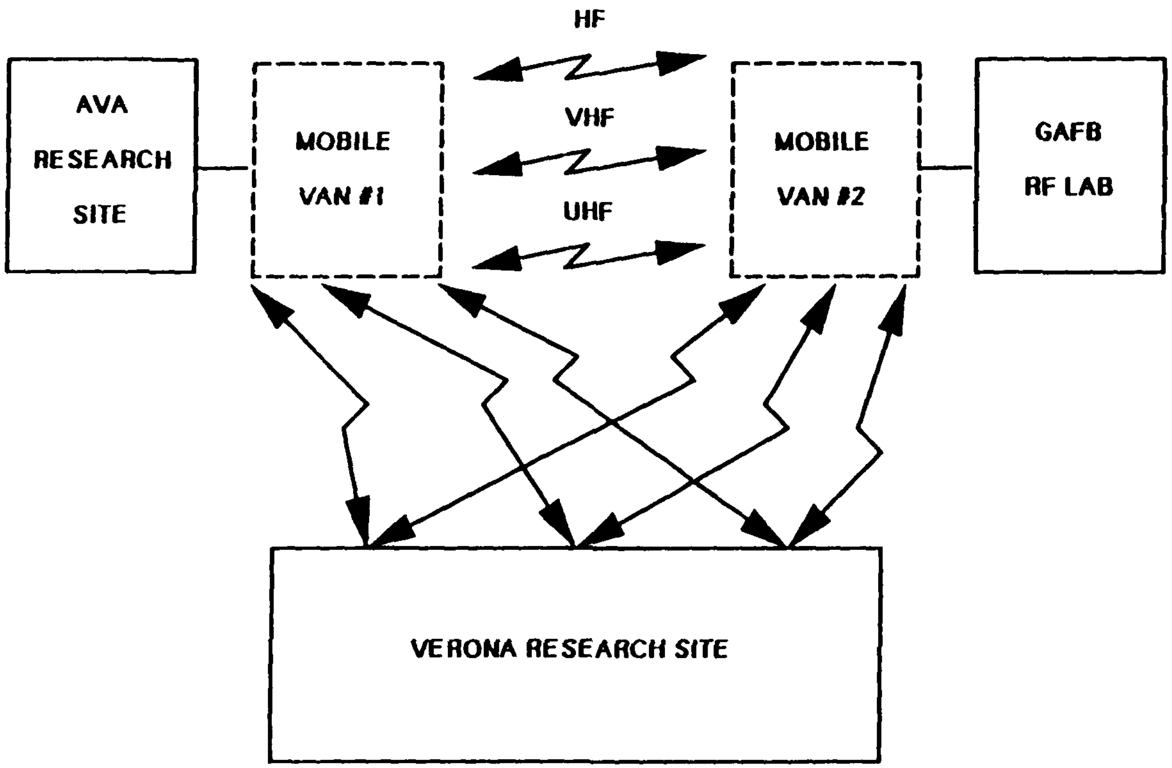


FIGURE 3. UPGRADED MULTIMEDIA TESTBED, DEC 87

at Ava and readings were taken on the VSWR. The load resistor at Building 3 was changed from 320 ohms to 426 ohms. The readings at Verona and Griffiss were improved, but it was thought they could still be better. The RF-7110 was run for awhile on the current configuration so that data would be available for comparisons. The antenna at Ava was then modified by loading all three legs with 106 ohm resistors. The RF-7110 was then reset. Likewise, at Building 3, all three legs were loaded with 106 ohm resistors and a jumper was placed onto the base of the antenna. Later, the 106 ohm resistors were removed from two of the legs. In each case, an LQA was run for comparison. The load at Verona was changed from 320 ohms to 106 ohms. The antenna was then rotated 90 degrees, but it did not give good results, so it was rotated back. Of all the variations, the last one implemented at Griffiss appeared to be the best. The antenna at Ava was changed to match that configuration, which had a three-ounce balun, a jumper across the base, and one leg loaded at 106 ohms. The antenna at Verona was similarly configured. Much data was taken on this latest configuration and entered into the computer for comparison.

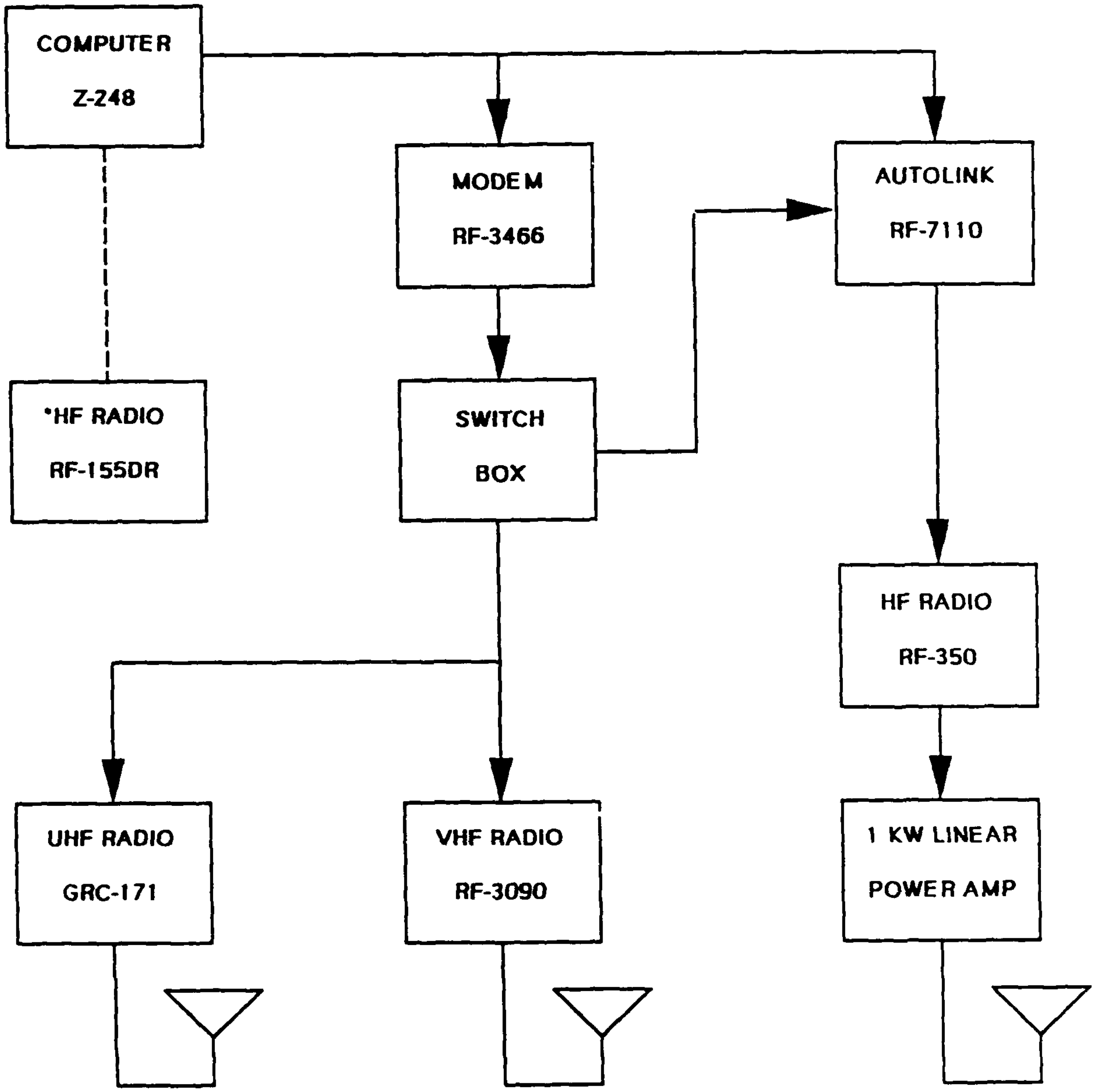
Cable fabrication continued in December. The last patch panel and interface cables were built. Three fiber optic cables were installed between the Photonics Laboratory and the RF lab. Cables were also made to interface the Z-248 to the VME system so that work with them could begin.

Significant progress was realized in 1987 (Figure 3), despite numerous configuration changes and support tasks on which much manpower was expended. Some of the most time-consuming of these support tasks were the maintenance and repair of the equipment in stock, the ordering of new equipment and supplies, and the frequent demonstrations of current capabilities. Although not evident from viewing the current facility, these tasks must be recognized as considerable progress in the system's fabrication, along with the tremendous learning curve

experienced by the engineers and technicians working on the project. Much more has been accomplished than is immediately obvious from a tour of the facility or a demonstration of its operation.

CURRENT CAPABILITIES AND EQUIPMENT:

At the end of 1987, the M^2C^2 consists of a three node (two mobile, one fixed) network that exploits packet radio technology to provide error free, ASCII and binary file transfers, as well as voice communications. Each node, configured as shown in Figure 4, is computer controlled to provide variable packet length, store-and-forwarding, forward error correction (FEC), and alternate routing. The length of the packets is a function of the ACKs and NACKs from the receive end. For every ACK that is received by the send end, the packet length is increased 64 bytes. For every NACK received, the packet length is halved. The store-and-forwarding function is performed message by message. The message is completed at the intermediate node before it is relayed to the next node. The alternative is performing it packet by packet, which is much more involved, but yields a higher throughput. The FEC is performed two ways. Additional bits are transmitted with the original data in order to decrease the probability of an error (or hit) on a data bit and to segment the data so that a hit may be located and corrected transparent to the user. The second form of FEC is performed by the Harris RF-3466 HF modem, which is being used for each media at this point. The modem performs interleaving which creates a more random pattern of hits so that errors are more easily corrected. The alternate routing is also performed in two ways. If node one is transmitting over a particular media to node two and the link fails, the software will automatically switch media after 10 NACKs and attempt to complete the transmission. The alternative is to attempt to reroute the traffic through a third node (1-3-2/2-3-1). Another important piece of software is contained in the Harris RF-7110, which performs a link quality



*THE RF-155DR WAS REMOVED FROM THE SYSTEM TEMPORARILY IN ORDER TO UTILIZE THE RF-7110 WHICH SUPPORTS THE RF-350

FIGURE 4. NODE CONFIGURATION, DEC 87

analysis. With this software, selected frequencies can be evaluated for their ability to carry traffic, not only in a standard mode, but also in a spread spectrum mode. All of these features combine to constitute a powerful transmission capability, with tremendous potential for expansion.

The current inventory of the Multimedia project is described below. All of the items are off-the-shelf equipments so that this work may be easily duplicated. This inventory will be expanded at every opportunity, within the constraints of funding and equipment availability.

HF RADIO SYSTEMS - There are currently two HF radio systems in use in the M^2C^2 facility. These are the Harris RF-155DR Data Radio Set and the Harris RF-350K Transceiver. An Autolink Controller, the Harris RF-7110, was also obtained to increase the transmission efficiency of the HF medium. The RF-7110 supports the RF-350K, but does not support the RF-155DR.

RF-155DR DATA RADIO SET - This radio set consists of the RF-1310 exciter, RF-590 receiver, RF-110A RF amplifier, RF-130-01 1KW transmitter, RF-124 power supply, and RF-601A antenna coupler (Figure 5). The equipment operates in the frequency range of 1.6 to 30 MHz, with a power output of 1KW. Operation at all locations is with a standard 30-foot whip antenna or the RF-1912A long wire antenna. This radio set has been specifically designed to accommodate high speed data communications, but transmission of audio and continuous wave (CW) signals are also possibilities.

The output signals from the modem are inserted into the exciter through the transmit audio assembly, where the modulated RF signal is produced. This RF signal is then fed to the RF amplifier where it is amplified and then sent to the 1-KW power amplifier. The output of the

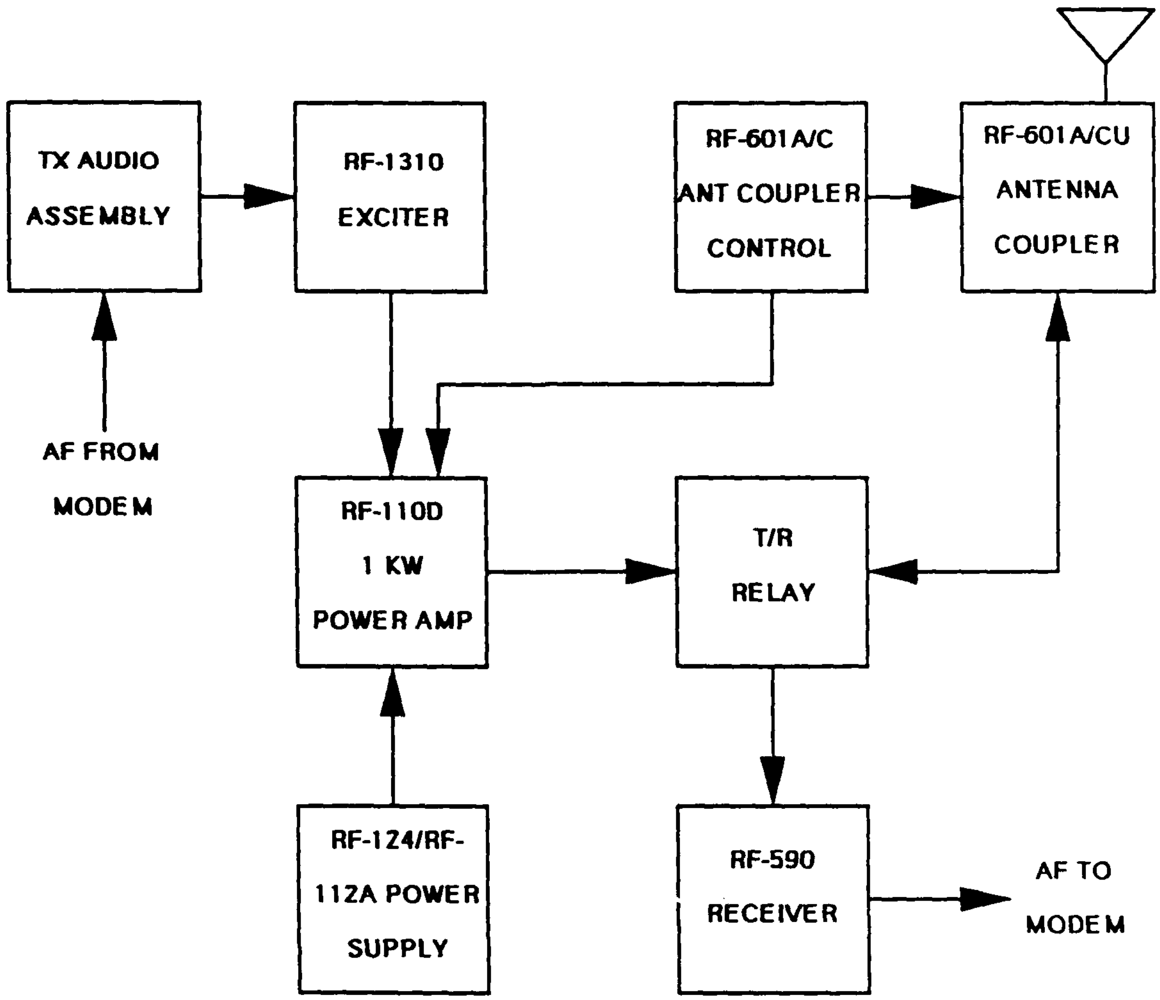


FIGURE 5. RF-155DR DATA RADIO SET BLOCK DIAGRAM

power amplifier is coupled to the antenna, via the T/R relay, through the antenna coupler which automatically matches the amplifier output impedance to the antenna impedance electronically. On the receive side, the receive signals are coupled from the antenna to the receiver through the antenna coupler and the T/R relay. The receiver converts the modulated RF signal back to the original signal and sends it directly to the modem.

In order for this equipment to accommodate transmission and reception of high speed data communications, such as Link-11 and TADIL-A/B formats, some modifications were performed. The specific modifications are the installation of the transmit audio assembly and the T/R relay. The transmit audio assembly provides a means of setting the modulation levels of the data envelope and also allows use of several keying schemes which include high speed data, normal upper sideband (USB) and lower sideband (LSB) audio, normal frequency shift keying (FSK) audio and a CW keyline. The internal antenna relay in the RF-110A RF amplifier has also been by-passed and replaced with the T/R relay. The time delay, which allowed use of the internal relay, was shortened to permit a rapid risetime of the signal envelope as provided by the external T/R relay. This external T/R relay provides rapid switching of the antenna to the transmitter and receiver.

RF-350K TRANSCEIVER - This transceiver consists of the RF-350 transceiver, RF-366 power supply, RF-351 or RF-601A antenna coupler, and the T/R relay (Figure 6). The unit is a solid state, synthesized, single sideband (SSB) transceiver operating in the frequency range of 1.6 to 30 MHz, tunable in 10 Hz steps, with an output power of 100 watts. The unit can be operated in the 100W mode with an RF-351 antenna coupler or in a 1KW mode with an RF-601A antenna coupler terminated into a standard 30-foot whip antenna or the RF-1912A long wire antenna. The currently installed equipments operate in the 1KW mode in both M^2C^2 shelters and the RF lab and in the 100W mode in Lab 2 at the Verona

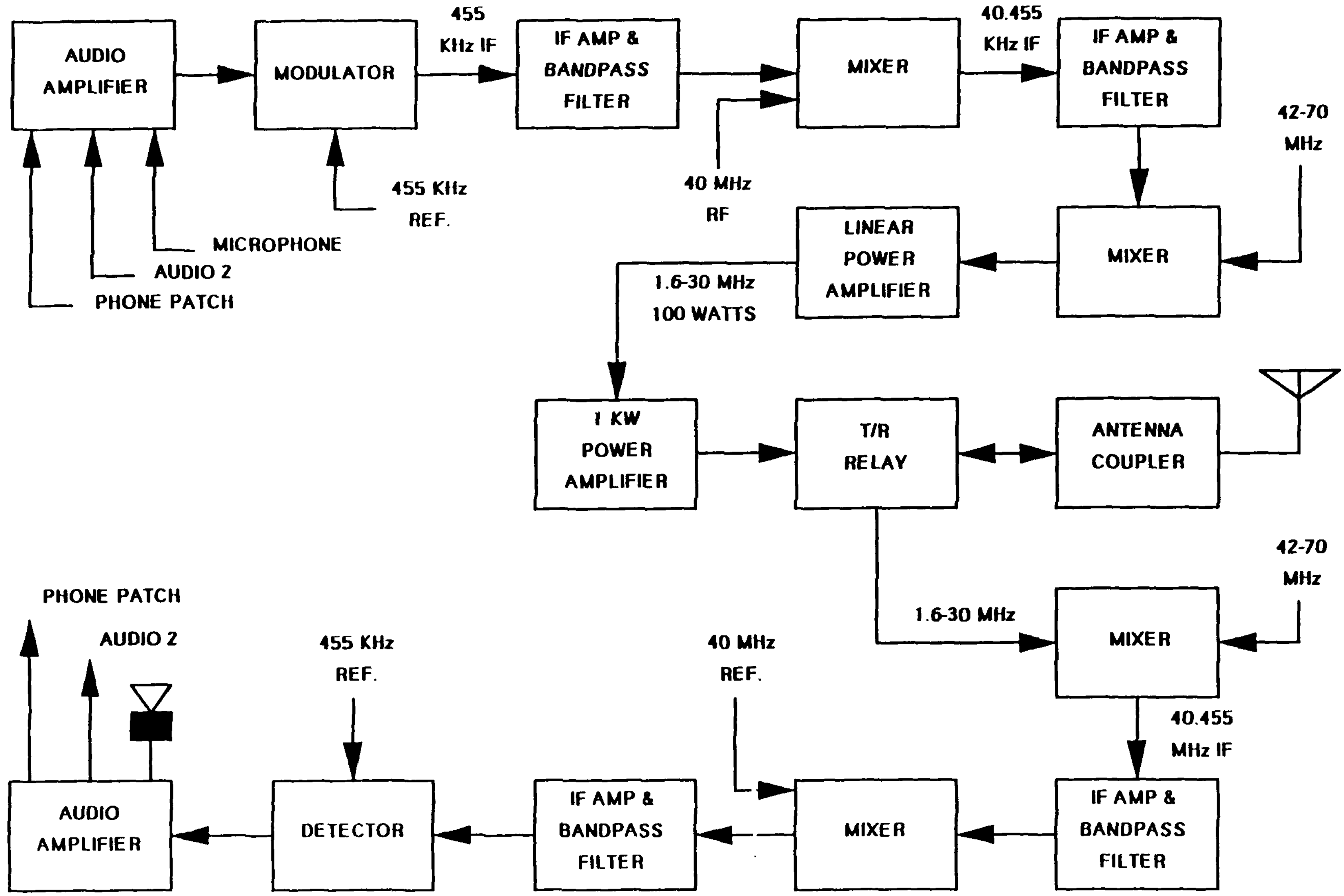


FIGURE 6. RF-350K TRANSCEIVER BLOCK DIAGRAM

Research Site. The RF-350K also contains a built-in test (BITE) feature which is initiated from the front panel and locates malfunctions down to replaceable assemblies and subassemblies.

The input signal is front panel selectable from either the front panel HANDSET/MIC input jack, AUDIO 2 from external equipment such as modems, or PATCH from two or four-wire telephone type circuits. This input signal is amplified and fed to a modulator where it is converted to an intermediate frequency (IF) of 455 KHz. This IF signal is then amplified again, passed through a bandpass filter, leveled by an automatic level control (ALC) circuit, and then converted to a second IF of 40.455 MHz. This second IF is also amplified and filtered, and then converted to the transmit frequency. The modulated output frequency is leveled by a transmitter gain control (TGC) circuit before it is amplified to the output level of 100 watts. The output is then fed to the antenna via the T/R relay and the antenna coupler. If the 1KW mode of operation is being utilized, the output of the transceiver is fed to the 1KW power ampifier where the signal is again amplified before going to the antenna coupler, via the T/R relay, and to the antenna. The receive signal from the antenna passes through a low pass filter and the T/R relay, where it is connected to the input of the receiver. The signal is then fed to a mixer where it is converted to an IF of 40.455 MHz, which is then filtered, amplified, and leveled by an automatic gain control (AGC) circuit. The 40.455 MHz signal is then applied to a second mixer where it is converted into an IF of 455 MHz. This signal is amplified, passed through a bandpass filter, and leveled by an additional AGC circuit. The IF is then fed to a demodulation circuit whose audio output is applied to the front speaker and the rear panel terminals for external equipment.

RF-7110 AUTOLINK CONTROLLER - This autolink controller is an HF channel quality indicator. It rank orders frequencies according to their ability to successfully carry data. It does this by a type of

chirpsounding where known data is transmitted and the integrity of the received signal is evaluated. This process is termed a Link Quality Analysis (LQA). The controller analyzes entered frequencies individually, from the highest to the lowest, and can handle up to 100 frequencies. The multimedia facility utilizes 10 frequencies in the range of 2 to 30 MHz. The controller ranks these frequencies through use of the RF-350K, as it will not support the RF-155DR without additional modifications. The controller is also capable of performing automatic HF link establishment and selective calling.

VHF RADIO SYSTEM - The VHF radio in use at the M^2C^2 facility is the Harris RF-3090V. This radio set consists of the RF-3090R/T (receiver/transmitter), RF-3090AU (adapter unit), RF-3090PA 50W power amplifier, RF-3017 handset, and RF-388 mobile antenna. The set is a VHF-FM vehicular transceiver which operates in the 30 to 90-MHz frequency range with an output power of 50 watts. The radio provides up to 2,400 channels, spaced 25 KHz apart, and is microprocessor controlled for eight channels with one channel for manual selection and seven channels which are preprogrammed. There are currently three radio sets installed at the M^2C^2 facility. One unit, operating as a base station with the RF-3090PS base station power supply, is installed in the RF lab. The other two units have been installed in the mobile shelters. The unit contains a self-test function to quickly locate a fault within the radio and return it to service.

When the radio is keyed, the transmit signal path is activated (Figure 7). The input signal is amplified in the front panel before going to the A5, audio module, where it is filtered, amplified, and a 150 Hz tone added for tone squelch. The audio/data signal then passes to the primary frequency synthesizer module, A7, where it is amplified and combined with a DC control signal to control the Voltage Controlled Oscillator (VCO) on the transmitter module, A9. The output of this VCO is the modulated transmit RF signal which is first buffered and then

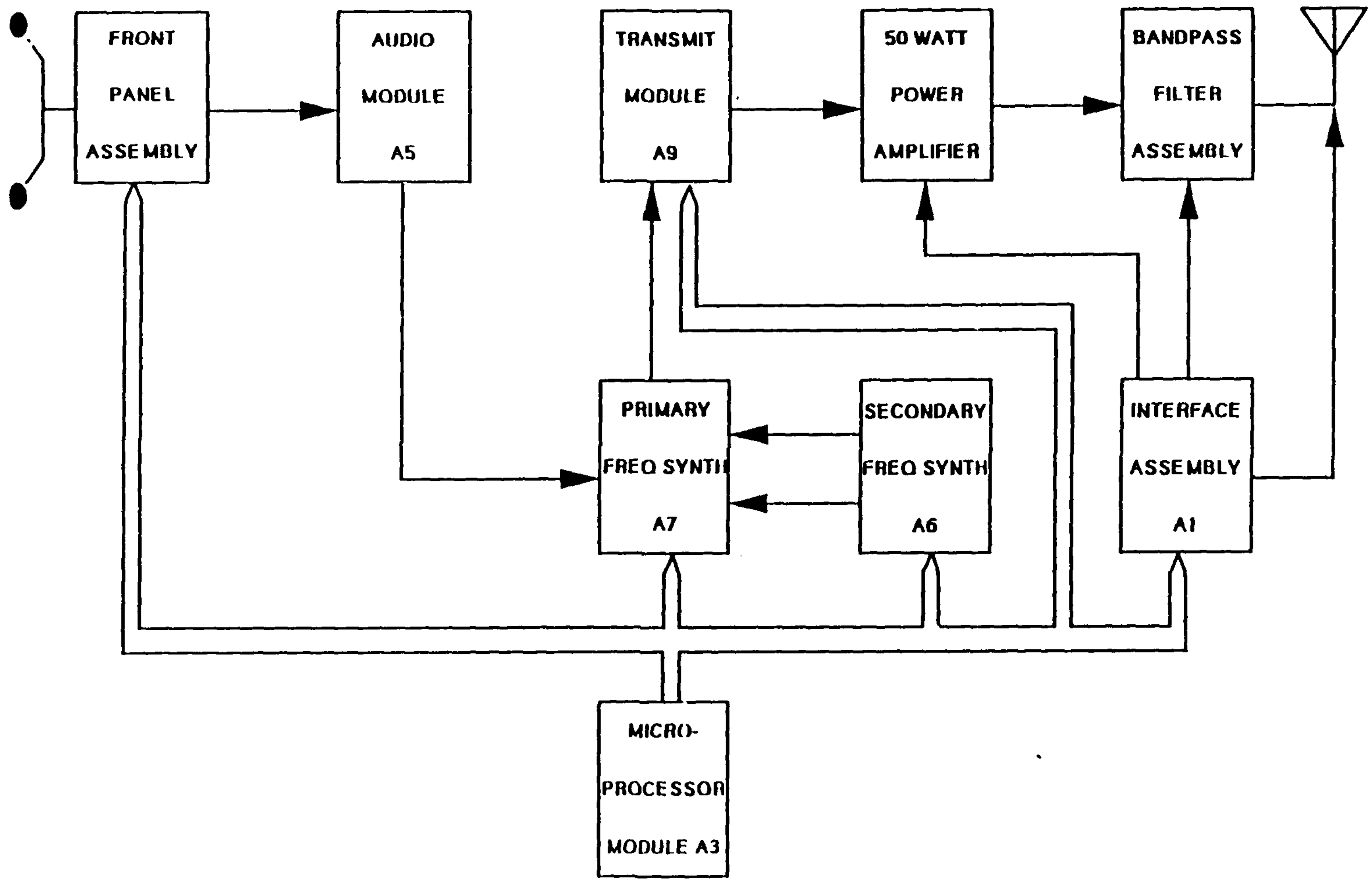


FIGURE 7. RF-3090V/TRANSMIT PATH BLOCK DIAGRAM

amplified. Relays in the A9 module switch the RF signal to either the "HIGH" or the "LOW" path as determined by the "XMT POWER" switch setting on the front panel. In the "LOW" setting, the 1W signal is coupled directly to the harmonic filter; in the "HIGH" setting, the 1W signal is first amplified to 10 watts before being coupled to the harmonic filter. The RF signal is next filtered to attenuate any RF transmit harmonics. If the "XMT POWER" switch on the front panel is in the "LOW" position, the signal is fed directly to the adapter unit bandpass filter assemblies and then to the antenna for transmission. If the "XMT POWER" switch is in the "HIGH" position, the signal is fed to the 50W power amplifier where it is amplified before being sent to the bandpass assemblies and subsequently transmitted.

The receive path is somewhat different (Figure 8). When a signal is received, it is first filtered in the bandpass filter assembly to attenuate any unwanted signals. After filtering, the signal is connected to the transmitter module, A9, where any harmonics above 90 MHz are filtered out before being sent to the receive module, A8. In this module, the signal is again filtered through a tuned preselector and converted to the first IF of 21.4 MHz by mixing the RF signal with the output of the VCO. The IF signal is then amplified, filtered, and converted to the second IF of 400 KHz. This second IF is filtered, amplified, and then demodulated to produce the received audio/data signal which is sent to the audio module, A5. The audio module filters and amplifies the audio/data signal and detects the necessary squelch conditions. The power supply module, A4, then again amplifies the signal before being sent to the handset.

The primary and secondary frequency synthesizer modules, A7 and A6, work together in two phase-locked loops to provide the DC control voltage used with the voltage controlled oscillators. The radio set is also microprocessor controlled by the microprocessor module, A3. This module controls such functions as circuit switching, filter and

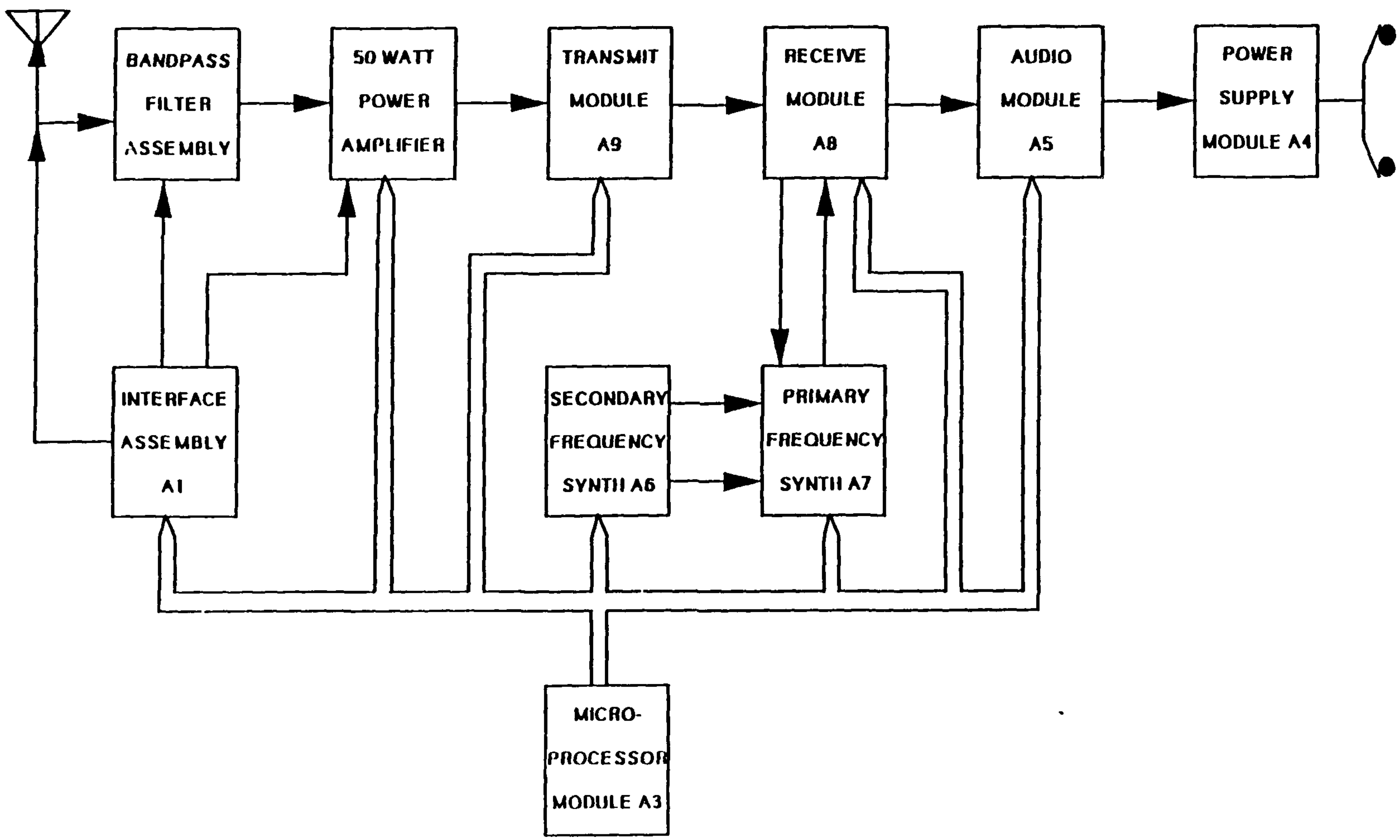


FIGURE 8. RF-3090V RECEIVE PATH BLOCK DIAGRAM

amplifier selection, pretune and divider data and loop status for both frequency synthesizers, squelch and muting functions, and antenna impedance matching.

UHF RADIO SYSTEM - There is currently only one UHF radio system in use at the M^2C^2 facility, the Collins AN/GRC-171B radio set (Figure 9). All sets are fully operational and are being utilized for the development of the M^2C^2 facility. This piece of equipment is a solid-state, multichannel transceiver that provides air-to-ground or point-to-point voice and data communications in both the AM and FM modes. The AN/GRC-171B operates in the 225 to 400 MHz range and provides 7,000 channels with a spacing of 25 KHz. Power output is 20 watts in the AM mode and 50 watts in the FM mode. The fact that the AN/GRC-171B was designed for use in both transportable and fixed station applications makes it exceptionally well suited for use in the M^2C^2 facility.

The transmitter section contains a broadband RF amplifier that amplifies the transmit RF signal to provide a nominal 20W carrier output when in the AM mode and a nominal 50W carrier output when in the FM mode. An ALC circuit receives forward and reflected signals to maintain control of the power output level. When operating in the AM mode, the transmit RF signal passes through an RF switch to the RF preamplifier/modulator. The audio signal to be transmitted is amplified and filtered by the audio circuits and then applied to the modulator of the power amplifier, where amplitude modulation takes place. When operating in the FM mode, the modulator is disabled to preclude amplitude modulation of the FM signal. In this mode, the transmit RF signal passes through the RF switch to a mixer. The audio signal to be transmitted is FM modulated on a 30-MHz signal produced by the VCO. This modulated 30-MHz signal is also applied to the mixer where it is combined with the transmit RF signal to produce the FM modulated transmit signal.

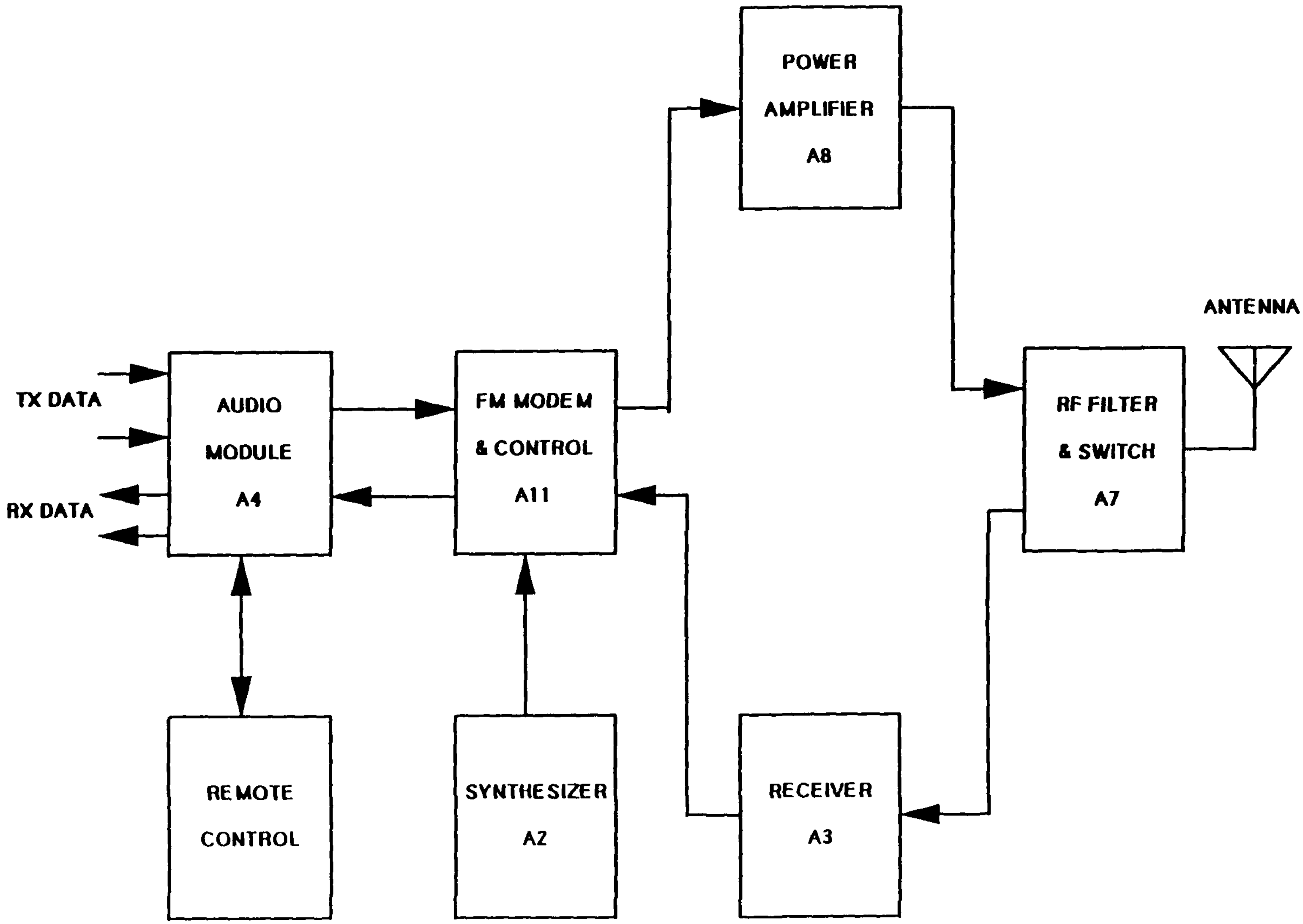


FIGURE 9. AN/GRC-171B UHF RADIO SET BLOCK DIAGRAM

When operating in the AM mode, the receiver section operates as a double-conversion receiver with a first IF of 30 MHz. The 30-MHz IF is derived by mixing the incoming received RF signal with a signal from the receiver synthesizer. The 30-MHz IF signal is then mixed with a signal from a 19.3 MHz oscillator to derive a second IF signal of 10.7 MHz. This second IF signal is then AM detected to obtain the audio signal. The audio signal is then passed to either the headset or the audio circuits. When operating in the FM mode, the receiver section operates as a triple-conversion receiver. The first two stages of conversion are identical to the AM mode, except the AGC is disabled so that the IF amplifiers can operate at maximum gain to provide limiting. A third IF of 4.5 MHz is derived by mixing the 10.7 MHz IF with a signal from a 15.2 MHz oscillator. The 4.5 MHz IF is then frequency discriminated into the received audio signal, which is then sent to the audio circuits where it is amplified and filtered before being sent to the headset or the audio outputs.

MODEMS - At the inception of the M^2C^2 facility, it was necessary to interface commercial computers, utilizing commercial communications software, to various commercial radio sets. The purpose of this interfacing was to effect successful file transfers, both ASCII and binary, between computers over different RF media. During the development of this technique, several modems were procured and utilized between the computer and the RF equipment. All of these modems are of the commercial variety and remain as an integral part of the facility.

FREDERICK 1280R FSK MODEM - The first modem utilized for file transfers was the Frederick 1280R FSK modem. This unit is a microprocessor controlled FSK/FEK modem that operates in the FSK mode with shifts of 60 to 200 Hz and in the FEK mode with shifts from 60 to 3,000 MHz. The modem can be configured as a one or two channel modulator/demodulator. When configured in the two channel configuration, the demodulators can be used independently or in

combination to provide diversity operation. Baud rates are selectable up to 1,200 baud. The 1280R was found to be non-compatible with the HF equipment and file transfers were not successful.

HAYES 1200B and 2400B SMARTMODEMS - The second modem utilized for file transfers was the Hayes 2400B Smartmodem. The 2400B is designed for operation over both dial-up and two-wire leased line circuits and capable of baud rates up to 2,400 bits per second (bps). Complete with its own communications program, Smartcom II, it is an intelligent data communications system that analyzes and executes commands, and sends result codes in optional English words or decimal digit form. Commands may be entered through the keyboard or can be issued through a program in most programming languages. All configuration settings are programmable and retained in a non-volatile memory. The Hayes 2400B was successfully used for transfer of both ASCII and binary files, however, only in a back-to-back configuration or over phone lines. In order for the modem to function, it required instantaneous acknowledgement from the distant end, which was not possible with the HF and UHF radio equipment due to delays introduced by antenna switching circuitry. It was then determined that the Hayes 1200B modem would be tried.

Two model 1200Bs were procured based on the known specifications of a unit already at RADC. This unit was designed for use on RF media as well as over normal telephone lines in that commands were available for a delayed acknowledgement. When the new units were received, they proved to be a later version that lacked the delayed acknowledgement capability. Operation of these modems produced the same results as that of the 2400B modems.

PAKRATT PK-232 - The PK-232 is designed to interface radio and computer or terminal equipment. The modem operates in five different modes (Morse, Baudot, ASCII, ANTOR/SITOR, or packet) at baud rates up to 9,600 bps. The PK-232 was selected at this time for use in the M^2C^2

facility because of its ability to interface with HF radio equipment. This unit is a five-mode protocol converter and data controller that includes built-in modems for all modes and can utilize any standard ASCII communications program. During the preliminary stages of computer file transfer experimentation, using the Z-248 with the RF-155DR HF radio system, limited success was realized with the PK-232 modem. Transfers of ASCII files were completed, but binary files could not be handled due to double packetization performed by the modem and the communications program. A tailored communications program was locally written by a Rome Research Corporation (RRC) programmer, which solved the packetization problem, allowing both ASCII and binary file transfer. The Harris RF-3466 high speed modem was then received and it was decided that this modem would be used in place of the PK-232.

HARRIS RF-3466 HIGH SPEED MODEM - The Harris RF-3466 high speed modem has been chosen as the best modem to meet the present operational requirements of the M^2C^2 facility. This modem was specifically designed for use with the Harris HF radio equipment in use. The modem was designed to be used with any HF simplex link and does not require a handshake from the distant end. It will operate equally well with ASCII or binary files. The unit uses quadrature phase shift keying (QPSK) to modulate 39 tones and a Reed-Solomon code to provide forward error correction (FEC). Interleaving of the data blocks is used to minimize burst errors and dual channel diversity capability at all available data rates enhances the probability of successful transmission. This technique reduces errors in environments subject to selective fading and low signal-to-noise ratios. Doppler shifts of up to 75 Hz are automatically corrected and all operating modes can be controlled from the front panel or by remote control.

COMPUTING SYSTEMS - This project began with a very basic configuration involving a Zenith Z-248 Personal Computer (PC) which performed all the necessary control functions and processing, as well as

the file serving. Now that the Multimedia facility and personnel have advanced, a Motorola VME system will be incorporated into the system to exploit its multi-tasking capabilities and speed. The Z-248 will be retained as a file server and storage device.

ZENITH Z-248 COMPUTER SYSTEM - The Z-248 is a commercial PC which was purchased for the initial set-up of the M^2C^2 facility. The Z-248 system consists of the computer and keyboard, a RGB monitor, and a printer. The computer came equipped with dual floppy disk drives and a Winchester hard disk drive has been added. The computer, a 16-bit microprocessor, has 512 KB (kilobytes) of Random Access Memory (RAM) and a mass storage capacity of 360 KB on the floppy disk drives and 21 MB (megabytes) on the Winchester drive.

VME BUS COMPUTER - The most important feature of the VME system is its one gigabyte wide bus which allows multiprocessing at very great speeds. This bus has many ports which can accommodate several types of protocols (multiple RS-232 (up to 128), RS-422, RS-423, IEEE-488, 802.3, X.25, 15.53 (aircraft)). The bus is arbitrating so that it can support priority protocols as well. The VME has a Unix-based operating system which employs a 16-MHz, 32-bit microprocessor, the 68020. The system also has a 70-MB hard disk, a 720-KB floppy drive, a tape transport deck with a controller, and a color graphics terminal. The system is powered by a 750W power supply and is rack mountable. The incorporation of this system into the M^2C^2 facility will open numerous possibilities which have not even begun to be explored.

AGE (AEROSPACE GROUND EQUIPMENT) - In addition to the two 5-KW generators which are part of the M^2C^2 communications shelters, the M^2C^2 facility also has a trailer mounted, 15-KW generator. The unit provides 220 volts, 3 phase, can be towed behind either the M-35 or the M-885 vehicles, and is diesel powered.

FUTURE WORK

Future work on the multimedia project is aimed at increasing the system's capabilities through the upgrade and transfer of the system software and the addition of appropriate state-of-the-art equipment that becomes available. The current system software was written in assembly language and will be translated into "C" to operate on the UNIX-based VME systems. The structure of the VME system will allow time-shared processing, significantly increasing processing speed. It is planned to commit a processor to each media to take full advantage of this feature. This will also lead to the ability to simultaneously transmit and receive from the facility. Another software development involves the use of a spread spectrum mode of transmission for either covert communications or to simply increase reliability at the cost of throughput. As the system and the software develops, some sort of intelligent network control will also be developed and implemented via an additional processor. This will entail the consideration of link availability, data rates, priority, etc., to maximize network performance, i.e., message delivery time, throughput. It is anticipated that a set of heuristics and/or artificial intelligence will be required. The most important bottleneck in hardware acquisition is the location of modems that allow the exploitation of the wide bandwidth and high data rates of certain media. Since one of the main ideas of this project is the use of off-the-shelf equipment, the search will continue. Another demonstration is planned for June to support the TARN. This demonstration will involve the use of all the multimedia capabilities as opposed to the previous demonstration where strictly HF was used.

All of the previous and future work on the multimedia project can be classified under one of the seven layers of the Open Systems Interconnection (OSI) model: physical, link, network, transport, session, presentation, and application layers (Figure 10). The physical layer involves the actual physical hardware and connections. The link

layer involves individual, point-to-point links, while the network layer is concerned with the overall use of these links. These three layers have been accomplished to some extent. By researching these seven layers, it is easier to see from where multimedia is coming and where it is going.

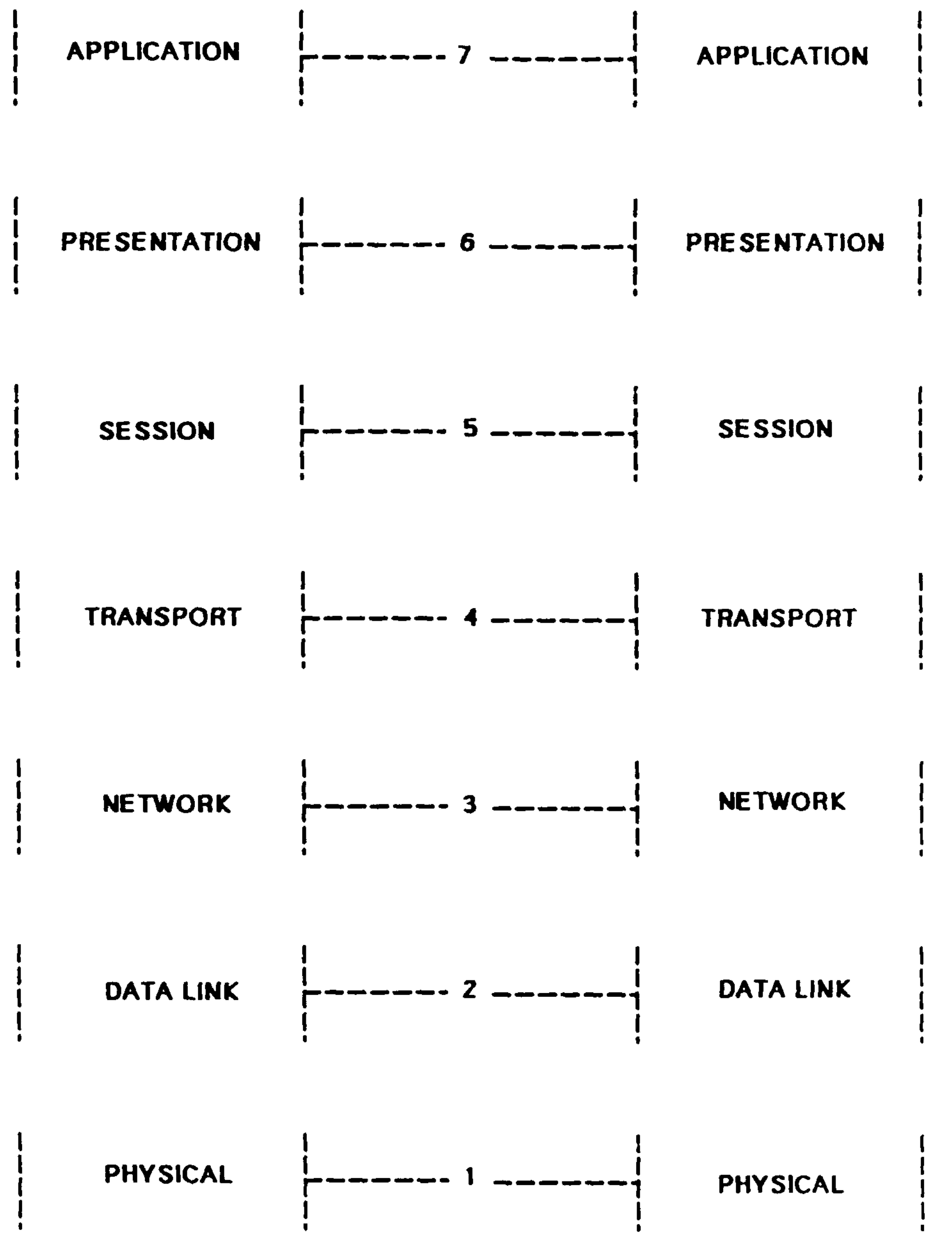


FIGURE 10. ISO MODEL FOR OPEN SYSTEMS INTERCONNECTION